


FORM PTO-1390 U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE (REV. 1-98)		ATTORNEY'S DOCKET NUMBER 47192/265185
<b>TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371</b>		U.S. APPLICATION NO. (If known, see 37 CFR 1.5) unknown/030009
INTERNATIONAL APPLICATION NO. PCT/EP00/03444	INTERNATIONAL FILING DATE 15 April 2000 (15.04.00)	PRIORITY DATE CLAIMED 29 April 1999 (29.04.99)
TITLE OF INVENTION CURRENT SENSOR WORKING IN ACCORDANCE WITH THE COMPENSATION PRINCIPLE		
APPLICANT(S) FOR DO/EO/US LENHARD, Friedrich, SCHÄFER, Stefan, MOURICK, Paul		
<p>Applicants herewith submit to the United States Designated/Elected Office (DO/EO/US) the following items and other information:</p> <ol style="list-style-type: none"> <li><input checked="" type="checkbox"/> This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.</li> <li><input type="checkbox"/> This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371.</li> <li><input type="checkbox"/> This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 37 (b) and PCT Articles 22 and 39(1).</li> <li><input checked="" type="checkbox"/> A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.</li> <li><input checked="" type="checkbox"/> A copy of the International Application as published (35 U.S.C. 371(c)(2))             <ol style="list-style-type: none"> <li><input type="checkbox"/> is transmitted herewith (required only if not transmitted by the International Bureau).</li> <li><input checked="" type="checkbox"/> has been transmitted by the International Bureau.</li> <li><input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US).</li> </ol> </li> <li><input checked="" type="checkbox"/> A translation of the published International Application into English (35 U.S.C. 371(c)(2)).</li> <li><input checked="" type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))             <ol style="list-style-type: none"> <li><input type="checkbox"/> are transmitted herewith (required only if not transmitted by the International Bureau).</li> <li><input type="checkbox"/> have been transmitted by the International Bureau.</li> <li><input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired.</li> <li><input checked="" type="checkbox"/> have not been made and will not be made.</li> </ol> </li> <li><input type="checkbox"/> A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).</li> <li><input checked="" type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). (unexecuted)</li> <li><input checked="" type="checkbox"/> A translation of the annexes of the International Preliminary Examination Report under PCT Article 36</li> <li><input type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.197 and 1.98</li> <li><input type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.</li> <li><input checked="" type="checkbox"/> A FIRST preliminary amendment.             <input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment.</li> <li><input type="checkbox"/> A substitute specification.</li> <li><input type="checkbox"/> A change of power of attorney and/or address letter.</li> <li><input checked="" type="checkbox"/> Other items or information:             <ol style="list-style-type: none"> <li>Certification Under 37 CFR 1.10</li> </ol> <p>I hereby certify that this document is being mailed to Box PCT, Commissioner for Patents, Washington, D.C. 20231, via "Express Mail Post Office to Addressee" on this 29th day of October, 2001, Express Mail Label No. EL209599074US</p> <p><u>Angela M. Rossi</u> Angela M. Rossi</p> <ol style="list-style-type: none"> <li>Form PCT/IB/308</li> <li>Version with markings to show changes made in claims</li> </ol> </li> </ol>		

U.S. APPLICATION NO. <b>10/030009</b> unknown		INTERNATIONAL APPLICATION NO. PCT/EP00/03444		ATTORNEY'S DOCKET NUMBER 47192/265185	
17. <input checked="" type="checkbox"/> The following fees are submitted BASIC NATIONAL FEE (37 CFR 1.492(a)(1)-(5)):				CALCULATIONS PTO USE ONLY	
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO				\$1,040.00	
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO				\$890.00	
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International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)				\$710.00	
International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4)				\$100.00	
<b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>				\$890.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input checked="" type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				\$130.00	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	\$	
Total claims	05	00	X \$18.00	\$ .00	
Independent claims	01	00	X \$84.00	\$ .00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ \$280.00	\$ .00	
<b>TOTAL OF ABOVE CALCULATIONS =</b>				\$1,020.00	
Reduction of 1/2 for filing by small entity, if applicable.				\$ .00	
<b>SUBTOTAL =</b>				\$1,020.00	
Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input checked="" type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				\$ .00	
<b>TOTAL NATIONAL FEE =</b>				\$1,020.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40 per property				\$ .00	
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				Amount to be refunded:	\$
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<p>NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b) must be filed and granted to restore the application to pending status.</p>					
Customer No. 23370					
SEND ALL CORRESPONDENCE TO: 					
23370					
John S. Pratt, Esq.					
KILPATRICK STOCKTON LLP PATENT TRADEMARK OFFICE					
1100 Peachtree Street, Suite 2800					
Atlanta, Georgia 30309-4530					
Name: Kristin D. Mallatt					
Registration No. 46,895					

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Lenhard, et al.

Serial No.: 10/030,009

Group Art Unit:

Filing Date: 29 October 2001

Examiner:

For: CURRENT SENSOR WORKING IN ACCORDANCE WITH  
THE COMPENSATION PRINCIPLE

Box PCT  
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Washington, D.C. 20231

Attorney Docket: 47192/265185

Date: 2/15/02

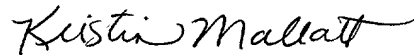
SECOND PRELIMINARY AMENDMENT

Preliminary to any examination on the merits, Applicants respectfully submit the following amendments:

On page 1, immediately following the title "Current Sensor Working in Accordance with the Compensation Principle" kindly insert the following paragraph:

--This application claims priority to German Application No. 199 19 602.8 filed on April 29, 1999 and International Application No. PCT/EP00/03444 filed on April 15, 2000 and published in German as International Publication No. WO 00/67040 on November 9, 2000, the entire contents of each are hereby incorporated by reference.--

Respectfully submitted,



Kristin D. Mallatt  
Reg. No. 46,895

OF COUNSEL:

KILPATRICK STOCKTON LLP  
1100 Peachtree Street  
Suite 2800  
Atlanta, GA 30309-4530  
404.815.6147

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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PRELIMINARY AMENDMENT

Preliminary to any examination on the merits, Applicants respectfully submit  
the following amendments:

In the Claims:

Kindly rewrite the claims as follows:

1. (Amended) A current sensor working in accordance with the  
compensation principle comprising:
  - a primary winding through which the current to be measured flows,  
creating a magnetic field,
  - a secondary winding, through which compensation current flows,  
which generates a magnetic field compensating the primary winding, whereby the  
primary winding and the secondary winding combined form a converter with certain  
resonance frequencies,
  - a terminating resistor connected in a series to the secondary winding,

sensor means, which are exposed to the resulting magnetic field of the primary and secondary coils,

a booster circuit, which is down-streamed to the sensor means at the input, and which feeds the compensation current to the secondary winding via the terminating resistor at the output, whereby the compensation current is pulse-duration modulated with a timing frequency above the resonance frequency of the converter, and

a low-pass filter arrangement for stabilizing the pulse-duration modulated compensation current, which is down-streamed to the booster circuit, comprising inductances and capacitances, which possesses a filter frequency threshold below the resonance frequency of the converter, and below the timing frequency of the booster circuit, as well as excessive resonance, whereby the excessive resonance of the low-pass filter arrangement is damped by an RC element connected in parallel to the secondary winding and the terminating resistor.

2. (Amended) The current sensor in accordance with claim 1, wherein the secondary winding is divided into a multitude of secondary coils, whereby the excessive voltages occurring between the secondary coils is limited by limiting means.

3. (Amended) The current sensor in accordance with claim 2, wherein the limiting means are Zener diodes, which are connected in a series, polarized in reverse order, and which are connected in parallel to the secondary coils.

4. (Amended) The current sensor in accordance with claim 1, wherein the booster circuit has at least one reverse timing power amplifier.

5. (Amended) The current sensor in accordance with claim 4, wherein the terminating resistor and the secondary winding are connected via a bridge circuit between reverse timing power amplifiers.

Version with markings to show changes made:

In the Claims:

Kindly amend the claims as follows:

1. (Amended) A [C]current sensor working in accordance with the compensation principle [with] comprising:
- a primary winding [(2)] through which the current to be measured flows, creating a magnetic field,
  - a secondary winding [(4)], through which compensation current flows, which generates a magnetic field compensating the primary winding, whereby the primary winding and the secondary winding combined form a converter with certain resonance frequencies,
  - a terminating resistor [(19)] connected in a series to the secondary winding,
  - sensor means [(7)], which are exposed to the resulting magnetic field of the primary and secondary coils,
  - a booster circuit [(8 through 12)], which is down-streamed to the [secondary winding] sensor means at the input, and which feeds the compensation current to the secondary winding [(4)] via the terminating resistor [(19)] at the output, whereby the compensation current is pulse-duration modulated with a timing frequency above the resonance frequency [(25)] of the converter, and
  - a low-pass filter arrangement [(17, 18)] for stabilizing the pulse-duration modulated compensation current, which is down-streamed to the booster circuit [(8 through 12)], [consists of] comprising inductances [(20, 21)] and capacitances [(22, 23)], which possesses a filter frequency threshold below the resonance frequency [(25)] of the converter, and below the timing frequency [(29)] of the booster circuit, as well as excessive resonance, whereby the excessive resonance

of the low-pass filter arrangement [(17, 18)] is damped by an RC element [(40)] connected in parallel to the secondary winding [(4)] and the terminating resistor [(19)].

2. (Amended) The [C]current sensor in accordance with [one of the] claim 1, [in that] wherein the secondary winding [(4)] is divided into a multitude of secondary coils [(5, 6)], whereby the excessive voltages occurring between the secondary coils [(5, 6)] is limited by limiting means [(44, 45)].

3. (Amended) The [C]current sensor in accordance with claim 2, [in that] wherein the limiting means are Zener diodes [(44)], which are connected in a series, polarized in reverse order, and which are connected in parallel to the secondary coils [(5, 6)].

4. (Amended) The [C]current sensor in accordance with [one of the] claim[s] 1 [through 3], [in that] wherein the booster circuit has at least one reverse timing power amplifier [(11, 12)].

5. (Amended) The [C]current sensor in accordance with claim 4, [in that] wherein the terminating resistor [(19)] and the secondary winding [(4)] are connected via a bridge circuit between [both] reverse timing power amplifiers [(11, 12)].

Remarks

Applicants submit that none of the above amendments are being made for reasons related to patentability, but are instead being made to put the application in proper format. No new matter has been added.

Respectfully submitted,



Kristin D. Mallatt  
Reg. No. 46,895

Date: October 29, 2001

OF COUNSEL:

KILPATRICK STOCKTON LLP  
1100 Peachtree Street  
Suite 2800  
Atlanta, GA 30309-4530  
404.815.6147  
Attorney Docket No.: 47192/265185



## Description

Current sensor working in accordance with the compensation principle

The invention relates to a current sensor working in accordance with the compensation principle with a primary winding through which the current to be measured flows, creating a magnetic field which can be compensated by compensation current flowing through a secondary winding, and by sensor means influenced by the magnetic field, which are down-streamed by a booster circuit, and which discharges the secondary winding connected in a series by a terminating resistor, with a pulse-duration modulated compensation signal.

Such a current sensor is known from DE-A-197 05 767. The known current sensor possesses a comparator, which is discharged at one comparator input with the measuring signal delivered by the sensor means, and on the other comparator input with a linear time base generated by a voltage generator. The comparator controls two reverse timing power amplifiers, between which the terminating resistor as well as the secondary winding is connected in a bridge circuit.

A current sensor is known from DE-OS-196 42 472, which uses a switchable booster for decreasing the power requirement for the compensation current, and for reducing the losses at an operation with excessive supply voltage, and which is controlled by a pulsing gating signal, which possesses a mark space ratio depending on the measured value.

EP-0 742 440 reveals a device for compensation current conversion, which uses a timed booster for the generation of the compensation current, which is connected in a series to a control amplifier. The pulse-duration modulated timer is then carried from an oscillator at

One of the disadvantages of the known current sensor is the fact that due to the frequency response of the booster circuit, only primary currents up to a certain upper frequency threshold can be measured. The current sensor can no longer follow the changes with frequencies of the primary current above the frequency threshold, so that the voltage does not drop via the terminating resistor, even though primary current is flowing through the primary winding.

Based on this state of technology, the task of the invention is to create a currency sensor, which can also be used at high primary current frequencies.

This task is solved by a current sensor in accordance with patent claim 1. The designs and improvements of the invention are subject of the sub-claims.

The pulse-duration modulated compensation signal possesses timing frequencies above the converter frequency threshold. The frequency response of the booster circuit at the existing current to be measured ensures a measurable voltage drop via the terminating resistor. Furthermore, a low-pass filter arrangement for stabilizing the pulse-duration modulated compensation current is intended, which is down-streamed to the booster circuit, and contains inductances and capacitances, a filter frequency threshold below the resonance frequency of the converter, and below the timing frequency of the booster circuit, and which possesses excessive resonance, whereby the excessive resonance of the low-pass filter arrangement is damped by an RC element connected in parallel to the secondary winding and the terminating resistor.

The invention therefore uses the fact that the current sensor works as a current converter at high primary current frequencies. The energizing magnetic field is increasingly

compensated at high primary current frequencies by the secondary currents flowing through the secondary winding caused by the reverse voltage. The secondary currents flowing through the secondary winding due to the converter behavior also result in a voltage drop at the terminating resistor. The voltage created at the terminating resistor due to the converter behavior gets stronger the higher the frequency of the primary current gets, in order to near the upper threshold value above the converter frequency threshold. In order for the current sensor relating to the invention to be usable independently of the primary current frequency, it must be ensured that no gap is formed in the frequency range between the converter behavior and the sensor behavior, in which the voltage at the terminating resistor drops substantially. This is achieved in particular by the timing frequencies of the pulse-duration modulated compensation signal being above the converter frequency threshold, and by the fact that the frequency response of the booster circuit, in particular that of the upper frequency threshold, also ensures a measurable voltage drop via the terminating resistor. Both measures combined ensure that a measurable voltage drop also occurs in a transition area between sensor behavior and converter behavior via the terminating resistor.

Additional beneficial designs and examples are subject to the attached claims.

The following examples of the invention are explained in detail in the attached drawing. They show:

Figure 1      the circuit of a current sensor with two reverse timing power amplifiers, between which a terminating resistor and the secondary winding are arranged a in a series with low-pass filters in a bridge circuit;

- Figure 2 a diagram, which shows the frequency threshold of the voltage dropping via the terminating resistor in dependency of the primary current frequency;
- Figure 3 a substitute circuit diagram for the bridge circuit from figure 1;
- Figure 4 a diagram, illustrating the frequency threshold of the voltage amplitude and the phase at the substitute circuit diagram from figure 3;
- Figure 5 a circuit of a current sensor, at which the excessive resonance caused by the low-pass filter is damped by an RC element;
- Figure 6 a diagram illustrating the frequency threshold and the amplitude of the bridge circuit from figure 5;
- Figure 7 a schematic illustration showing the different feedback between the primary winding and the secondary coil; and
- Figure 8 an additional current sensor, at which the excessive voltage between the secondary coils is limited via limiting means.

Figure 1 shows a current sensor 1 with a primary winding 2, through which the primary current  $I_p$  to be measured flows, both of which are coupled to two secondary coils 5 and 6 forming the secondary winding 4 via a magnetic core 3. The magnetic feedback between the primary winding 2 and the secondary coils 5 and 6 each is illustrated by the broken-lined arrows M1 and M2. The magnetic flow within the magnet core 3 is detected by a magnetic field sensor 7, which discharges a signal generator 8 for generating pulse-duration modulated booster signals Q and Q'. The booster signals Q and Q' are fed to the power amplifier circuits 9 and 10, each controlling transistors 13, forming two reverse timing power amplifiers 11 and 12. By converting the measuring signal of the magnetic field sensor 7 into the pulse-duration modulated compensation signals, any losses in the reverse timing power amplifiers 11 and 12 are minimized. The power transistors 13 are

each bypassed by freewheeling diodes 14 and directly connected to the feed wires 15 and 16. Low-pass filters 17 and 18, a terminating resistor 19, and the secondary coils 5 and 6 are arranged in the bridge circuit between the reverse timing power amplifiers 11 and 12. The low-pass filters 17 and 18 each contain coils 20 and 21 with down-streamed condensers 22 and 23 connected to mass.

Figure 2 explains the functions of the current sensor 1.

Figure 2 illustrates the frequency response of different voltage components dropping at the terminating resistor 19 depending on the frequency of the primary current  $I_p$ . A converter characteristic curve 24 represents the frequency dependency of that voltage component, which drops at the terminating resistor 19 due to the converter behavior of the current sensor 1. As the energized magnetic field is increasingly compensated by the secondary current flowing through the secondary coils 5 and 6 induced by a reverse voltage at increasing frequency of the primary current  $I$ , the voltage increasing at the terminating resistor 19 drops with increasing frequency. Due to the compensation of the magnetic flow of the current in the secondary coils 5 and 6, which increases with increasing frequency, the voltage component caused by the converter behavior finally reaches a maximum voltage 26 above a converter frequency 25.

The sensor characteristic curve 27 in figure 2 illustrates the frequency dependency of that voltage component dropping at the terminating resistor 19, which is caused by the sensor behavior of the current sensor 1. This voltage component is essentially consistent up to a certain sensor frequency threshold 28, in order to then drop above the sensor frequency

threshold 28 in the booster circuit, which is caused by the frequency threshold formed by the signal generator 8, timing power amplifiers 9 and 10 and the reverse timing power amplifiers 11 and 12. In order to ensure a voltage drop at each frequency of the primary current  $I_p$  at the terminating resistor 19, it is necessary to avoid any gaps in the transition area between the converter behavior and the sensor behavior. For this reason, the timing frequencies 29 of the pulse-duration modulated compensation signals Q and Q' should be above the converter frequency threshold 25, if possible. One possible area of timing frequencies 29 is illustrated in figure 2 by an arrow 30. The sensor frequency threshold 28 should also preferably be above the converter frequency threshold 25. However, if an interruption of the measuring voltage dropping at the terminating resistor 19 is calculated in, the sensor frequency threshold 28 may also be below the converter frequency threshold 25. It must be ensured, however, that the sensor frequency threshold 28 is not so low that the measuring voltage at the terminating resistor 19 interrupts so strongly that a gap is formed in the frequency response of the measuring voltage between the converter behavior and the sensor behavior.

The measuring voltage dropping at the terminating resistor 19 is usually measured with the aid of a differential amplifier connected to both ends of the terminating resistor 19. When the frequency response of the booster circuit, which consists of the signal generator 8, the power amplifier circuits 9 and 10 as well as the reverse timing power amplifiers 11 and 12, shows a sensor frequency threshold 28 above the timing frequencies 29, and the low-pass filters 17 and 18 are not available, a common mode voltage common with the voltage differential of the supply voltages and a frequency common to the timing frequency 29 is contiguous to the inputs of the differential amplifier via the terminating resistor 19. Typically, the differential amplifier would then

be loaded via a common-mode voltage of +/- 15 volts at a frequency of 400 kHz via the terminating resistor 19. The common-mode suppression of common operating amplifiers is usually unable to withstand such a common-mode load.

It is therefore beneficial to place the sensor frequency threshold 28 to values below the timing frequency 29. This results in preferred areas for the sensor frequency threshold 28 as illustrated in figure 2 by the arrow 31.

The sensor frequency threshold 28, for instance, can effectively be moved in small increments by the low-pass filters 17 and 18 as illustrated in figure 1. According to figure 1, this is done in the circuit by the low-pass filters 17 and 18 with the coils 20 and 21 as well as the condensers 22 and 23. Typical values for the inductance of the coils 20 and 21, and for the capacities of the condensers 22 and 23 are 68 to 100  $\mu$ H and 100 nF. One disadvantage of the circuit from figure 1 is that the low-pass filters 17 and 18 used contain a non-salient phase displacement. This can cause an undesirable regenerative feedback across the circuit magnetic field sensor 7, signal generator 8, timing power amplifier circuit 9 and 10, reverse timing power amplifiers 11 and 12, secondary winding 4, magnetic field sensor 7, whereby the circuit can oscillate freely at a frequency corresponding to the resonance frequency of the low-pass filters 17 and 18.

These facts are explained in detail in figures 3 and 4.

Figure 3 shows a substitute circuit diagram for the bridge circuit formed from the low-pass filters 17 and 18, the terminating resistor 19, and the secondary winding 4. The coil 20 of the low-pass filter 17 is illustrated by a filter inductance 32, a filter capacity 33, and a filter resistor 34. Accordingly, the secondary winding 4 is illustrated by a winding inductance 35, a winding capacitance 36, and a winding resistor 37. Figure 3 also shows

an RC element 40, illustrated by a broken line, formed by a resistor 38 and a capacity 39, which will be explained in details in another paragraph.

Figure 4 shows the task of the phase 41 and the voltage amplitude 42 of the measuring voltage  $U_{Rb}$  via the terminating resistor 19 in dependency of the frequency. The first phase jump by  $+180^\circ$  is created by the winding capacitance 36 in combination with the winding inductance 35, and is of secondary meaning. The second phase jump by  $-180^\circ$  is effected by the low-pass filter 17 and creates an excess of amplitude on the resonance frequency, on which the current sensor 1 can oscillate.

The following values were used for the simulation:

The filter inductance 32, the filter capacitance 33, and the filter resistor 34 were each set to the values 220  $\mu\text{H}$ , 10 pF and 0.5 ohm. Finally, the values 1 H, 50 pF, and 40 ohm were selected for the winding inductance 35, the winding capacitance 36, and the winding resistor 37.

Figure 5 shows how the excessive resonance was damped at the second phase jump by the RC element 40, shown as a broken line in figure 3. Typical values for the resistor 38, and the capacitance 39 are 65 ohm, and 200 nF. As figure 6 shows, the additional RC element 40 reduces the resonance quality, and thereby also reduces the excessive amplitude at the second phase jump, so that the 0 dB line is no longer achieved. Therefore, oscillations no longer occur in this case.

In an alternate, not illustrated example, the reduction of the excessive resonance is effected by a resistor, which is connected in parallel to a low-pass filter 17 and 18. This resistor connected in parallel can also stabilize the current sensor 1. However, the filter



characteristics of the low-pass filters 17 and 18 would have to be reduced for this purpose.

Another problem with regard to high frequencies of the primary current  $I_p$  is the possibility of fast transients of the primary current  $I_p$ . This is of particular meaning when the secondary winding 4 is arranged, for instance, into both secondary coils 5 and 6. Typically, the magnetic feedback between the primary winding 2 and the secondary coils 5 and 6 differs due to the mechanical construction of the current sensor 1, and the arrangement of the primary winding 2 with regard to the secondary coils 5 and 6. Figure 7 shows such a case. In this case, the primary winding 2 is a wire-like conductor 43, which is fed through the inner orifice of the ring-like magnetic core 3 in an arc. In the case illustrated in figure 7, the wire-like conductor 43 provides better feedback to the secondary coil 5 than to the secondary coil 6.

This results in the occurrence of an extremely high voltage at a very fast transient of the primary current  $I_p$ , i.e., at a large  $dI_p/dt$  at the center point between both secondary coils 5 and 6. This is due to the fact that different secondary currents are energized in the secondary coils 5 and 6 by the varying magnetic feedback  $M1$  and  $M2$  during the current increase. Because the secondary coil 5 and the secondary coil 6 are connected in a series, different secondary currents are possible only if excessive voltage is generated at the connection between both secondary coils 5 and 6. This excessive voltage can easily reach several kilovolts, and leads to at least a breakdown of the winding insulation of the secondary coils 5 and 6. It is therefore important to limit these excessive voltages.

Limitation of excessive voltage is done in the example illustrated in figure 8 by a few Zener diodes 44, which are connected in a series, and polarized in reverse order, which, together with an ohmic resistance 45, are connected in a series to the terminating resistor

19 and to the secondary coil 6. Typically, the breakdown voltage of the Zener diode 44 is at 390 v. In order for the limiting circuit not to become effective at a low  $dI_p/dt$ , it is beneficial if rather high breakdown voltages of the Zener diodes 44 are selected. Additional currents flow through this limitation circuit at excessive voltages via the terminating resistor 19. The measuring result at the terminating resistor 19 is slightly affected by this. However, this only occurs at high  $dI_p/dt$  of, for instance, over 100 A/ $\mu$ s. Generally, however, such fast transients only occur with short circuit currents. In these cases, however, no high accuracy in the measurement of the primary current  $I_p$  is necessary.

The ohmic resistance 45 limits the excessive voltage less harshly. The duration of the excessive voltage is limited at an ohmic resistance value of 1 kOhm to 10  $\mu$ s.

The limiting circuit is suitably applied across that of the two secondary coils 5 and 6, which provides the most feedback to the primary winding 2. However, it is also possible to include another corresponding limiting circuit across the secondary coil 6 in addition to the limiting circuit illustrated in figure 8. In the same way, it is possible not to connect the resistor 45 to the low-pass filter 17, but rather to the mass. However, in this solution the limiting currents do not flow across the limiting resistor 19, and can therefore not be detected.

Finally it should be noted that the principles and measures illustrated herein also apply to current sensors with only one booster power amplifier. It is possible, for instance, to omit the reverse timing power amplifier 11 as well as the low-pass filter 17 in the examples

illustrated in figures 1, 5, and 8, and to connect one end of the terminating resistor 19 to the mass.

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## New Patent Claims

1. Current sensor working in accordance with the compensation principle with a primary winding (2) through which the current to be measured flows, creating a magnetic field,

a secondary winding (4), through which compensation current flows, which generates a magnetic field compensating the primary winding, whereby the primary winding and the secondary winding combined form a converter with certain resonance frequencies,

a terminating resistor (19) connected in a series to the secondary winding, sensor means (7), which are exposed to the resulting magnetic field of the primary and secondary coils,

a booster circuit (8 through 12), which is down-streamed to the secondary winding (4) at the input, and which feeds the compensation current to the secondary winding (4) via the terminating resistor (19) at the output, whereby the compensation current is pulse-duration modulated with a timing frequency above the resonance frequency (25) of the converter, and

a low-pass filter arrangement (17, 18) for stabilizing the pulse-duration modulated compensation current, which is down-streamed to the booster circuit (8 through 12), consists of inductances (20, 21) and capacitances (22, 23), which possesses a filter frequency threshold below the resonance frequency (25) of the converter, and below the timing frequency (29) of the booster circuit, as well as excessive resonance, whereby

the excessive resonance of the low-pass filter arrangement (17, 18) is damped by an RC element (40) connected in parallel to the secondary winding (4) and the terminating resistor (19).

2. Current sensor in accordance with one of the claim 1, in that the secondary winding (4) is divided into a multitude of secondary coils (5, 6), whereby the excessive voltages occurring between the secondary coils (5, 6) is limited by limiting means (44, 45).

3. Current sensor in accordance with claim 2, in that the limiting means are Zener diodes (44), which are connected in a series, polarized in reverse order, and which are connected in parallel to the secondary coils (5, 6).

4. Current sensor in accordance with one of the claims 1 through 3, in that the booster circuit has at least one reverse timing power amplifier (11, 12).

5. Current sensor in accordance with claim 4, in that the terminating resistor (19) and the secondary winding (4) are connected via a bridge circuit between both reverse timing power amplifiers (11, 12).

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FIG 1

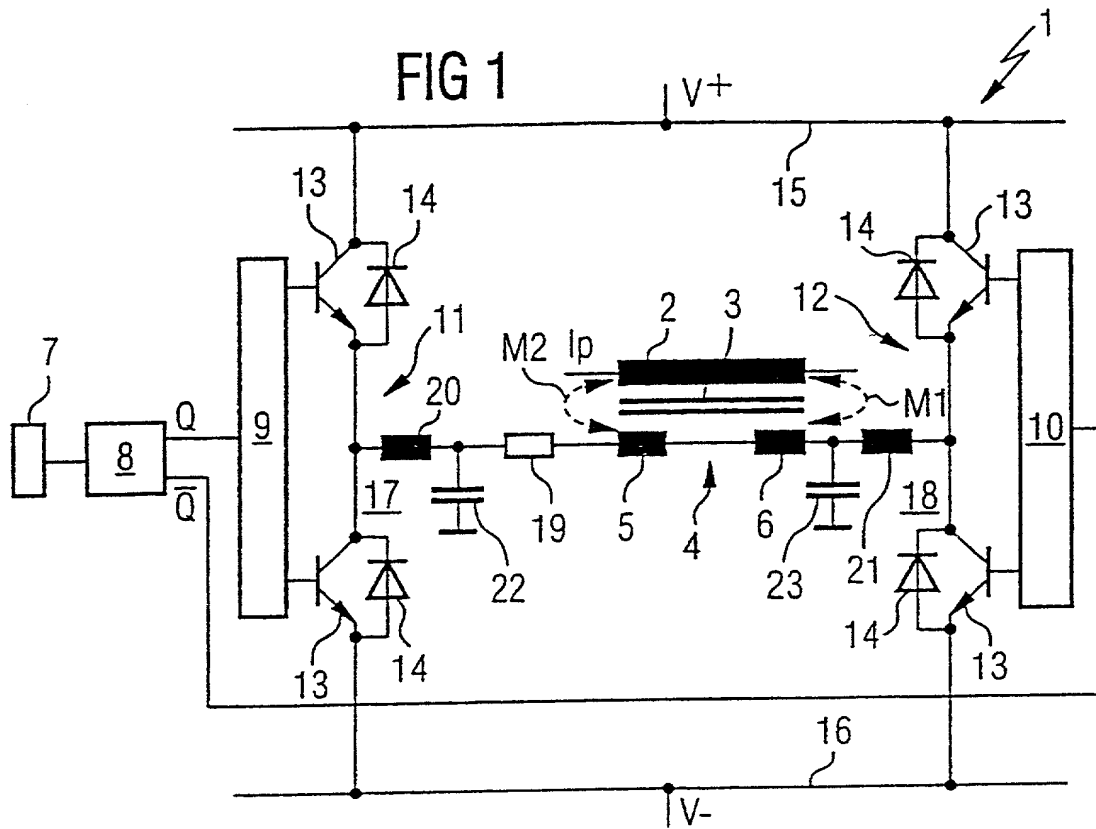
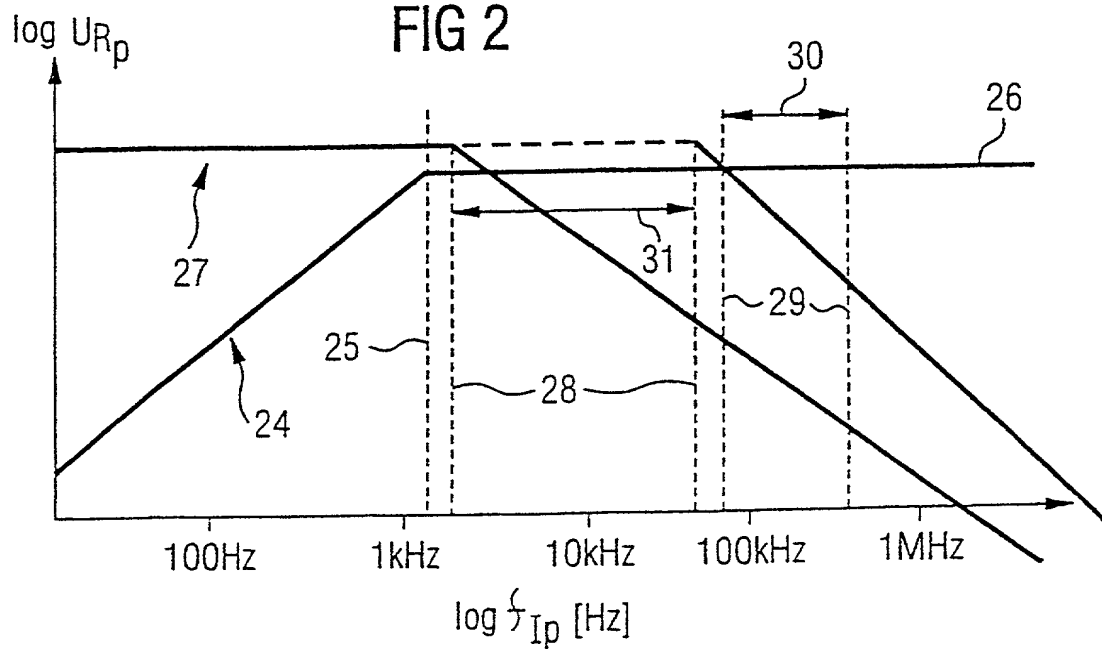


FIG 2



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FIG 3

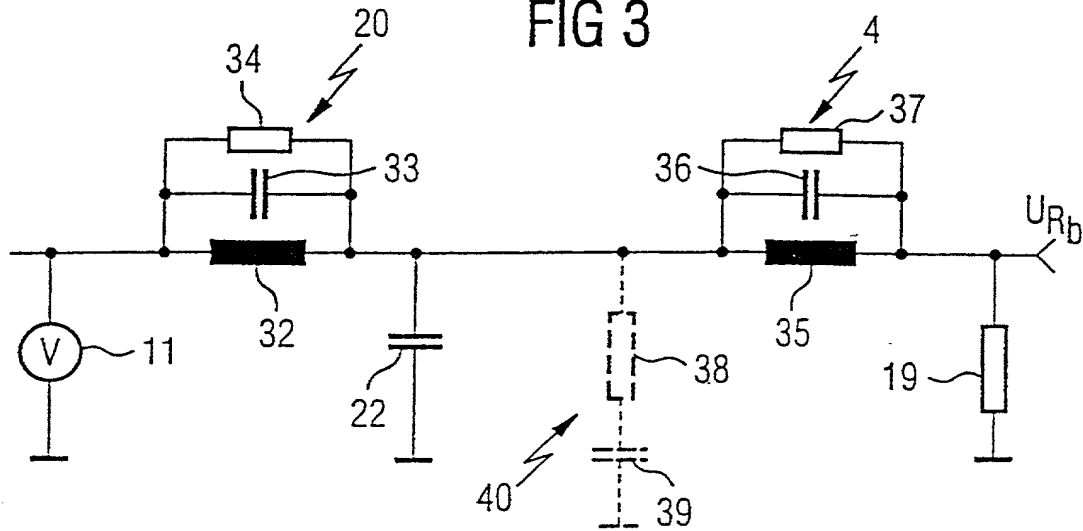


FIG 4

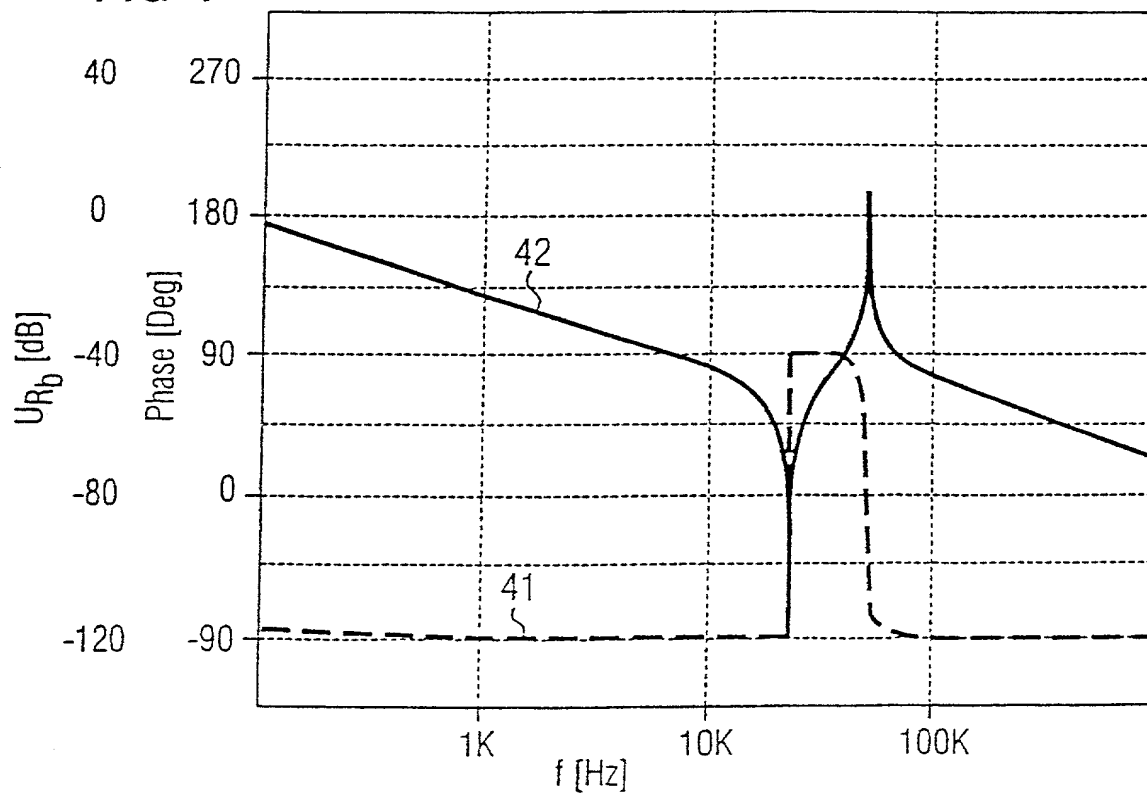


FIG 5

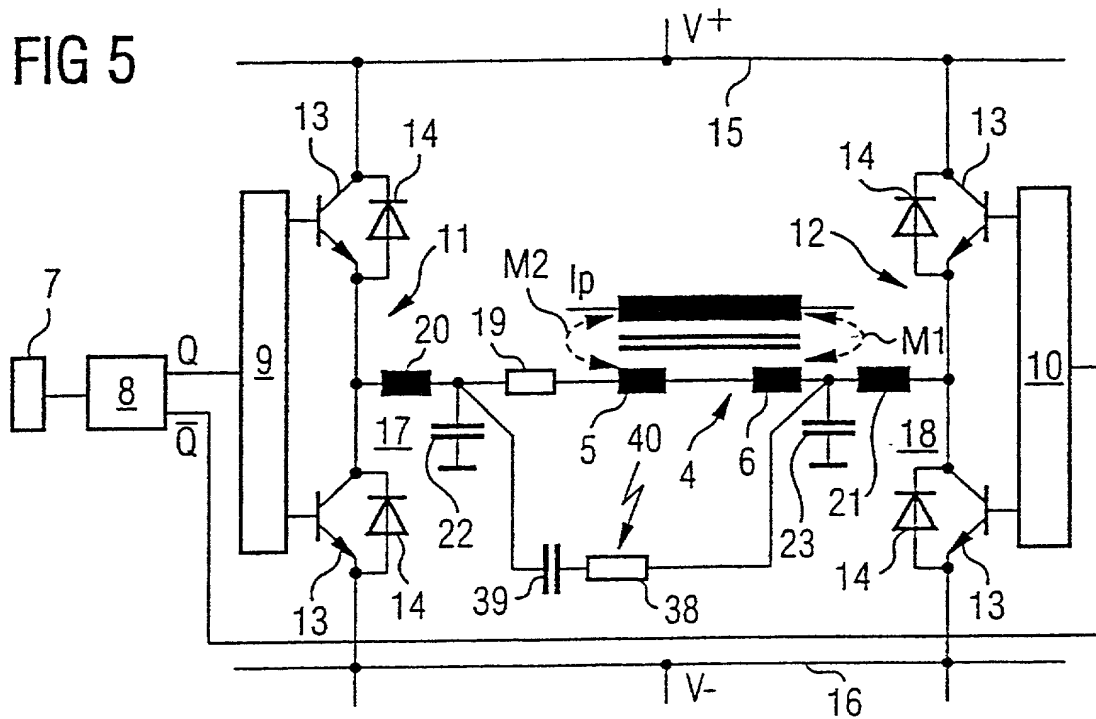
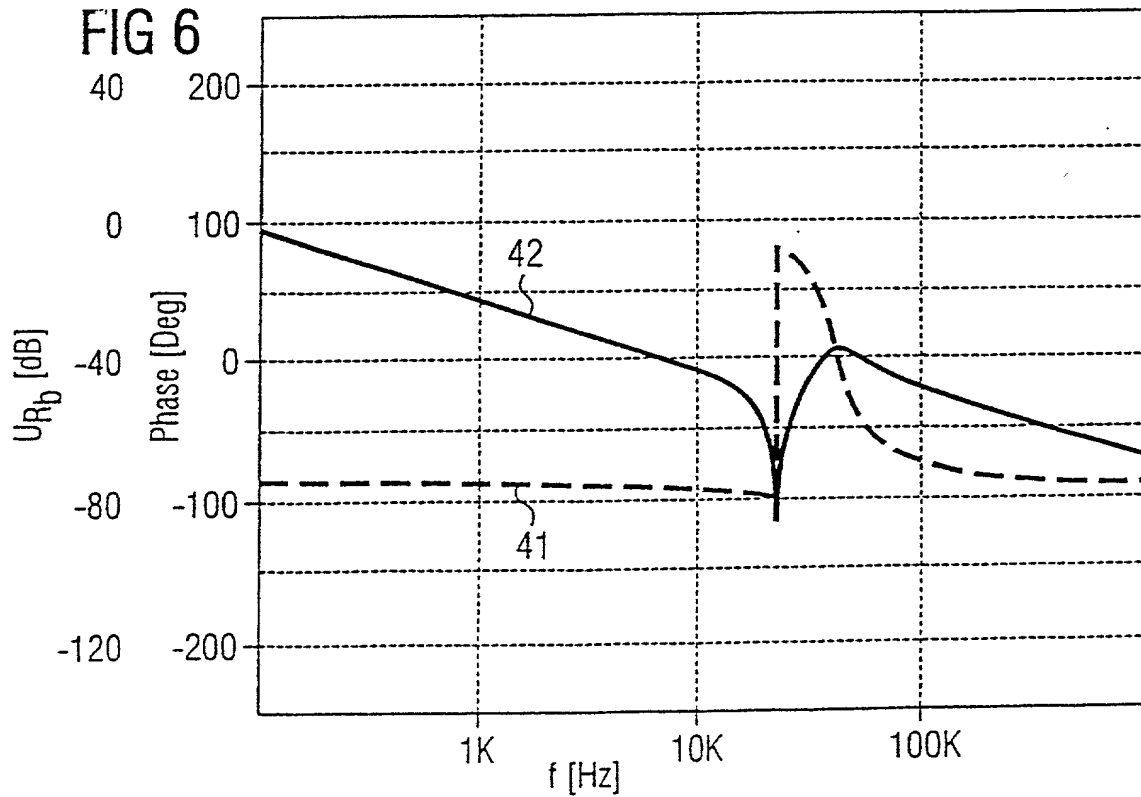


FIG 6





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FIG 7

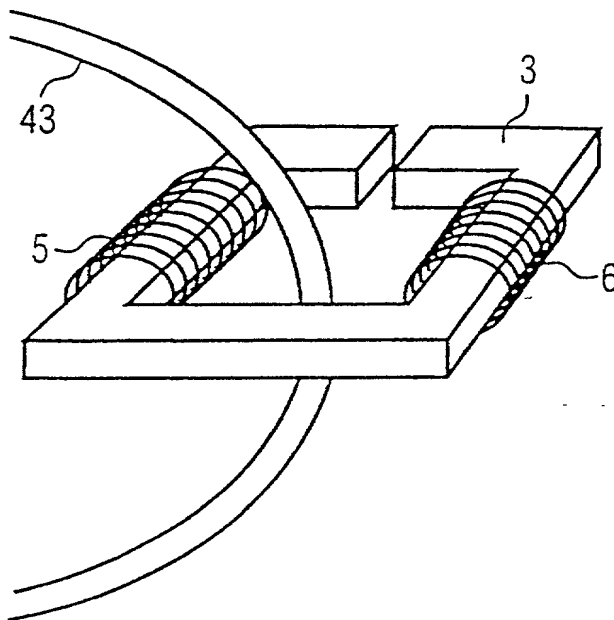
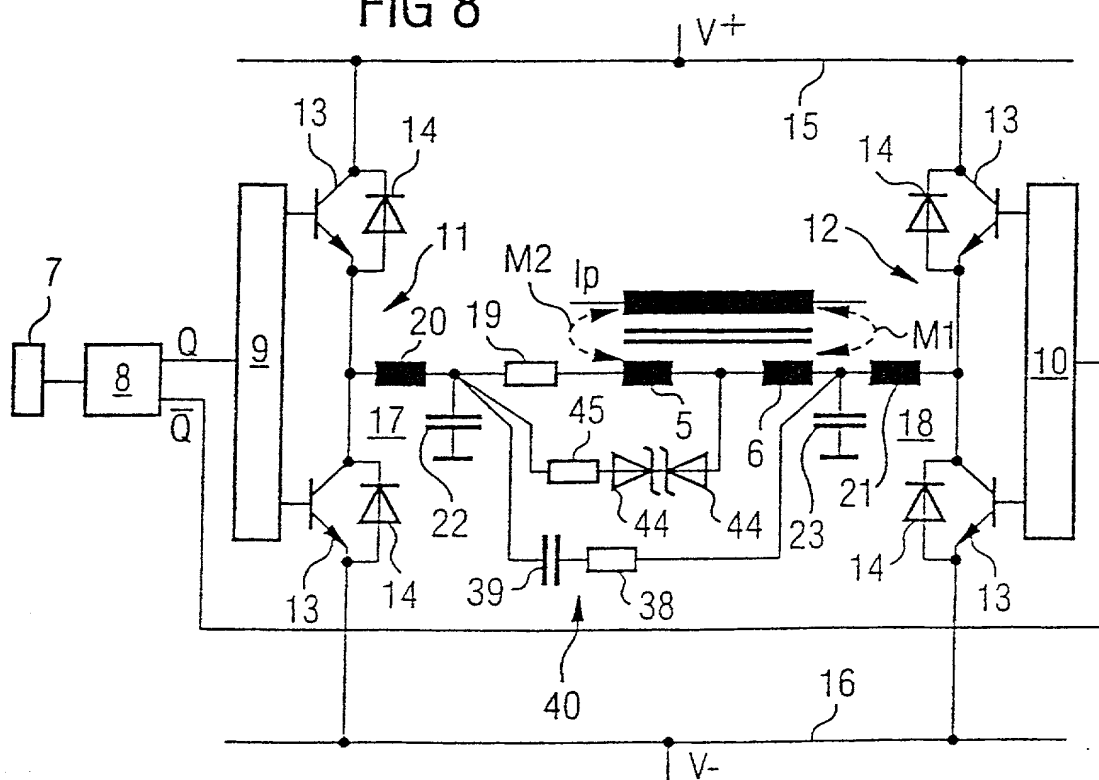


FIG 8



## DECLARATION FOR PATENT APPLICATION

☒ Original

☐ Supplemental

☐ Substitute

☐ PCT

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below), or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

Current Sensor Working in Accordance with the Compensation Principle

(Title of the Invention)

the specification of which (check one)

☐ is attached hereto

☒ was filed on 15 April 2000 as International Application No. PCT/EP00/03444

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 (a) - (d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified, by checking the box below, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Applications			Priority Claimed		Copy Attached	
Application Number	Country	Foreign Filing Date (MM/DD/YYYY)	YES	NO	YES	NO
199 19 602.8	DE	04/29/99 (April 29, 1999)	x			x

I hereby claim the benefit under Title 35, United States Code § 119(e) of any United States provisional application(s) listed below and claim the benefit under Title 35, United States Code, § 120 of any United States application(s), or § 365(c) of any PCT international application(s) designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application(s) in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

Filed: 26 October 2001

Inventors: Friedrich LENHARD, et al.

For: "Current Sensor Working in Accordance with the Compensation Principle"

Declaration for Patent Application

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Parent Application Number	Filing Date	Status (Mark Appropriate Column Below)		
		Patented	Pending	Abandoned

As a named inventor, I hereby revoke all prior powers and appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith:

FIRM NAME: KILPATRICK STOCKTON LLP, 1100 Peachtree Street, Suite 2800, Atlanta, Georgia 30309-4530

Attorney and/or Agent	Registration No.
Roger T. Frost	22,176
Charles Y. Lackey	22,707
Anthony B. Askew	24,154
John M. Harrington	25,592
Robert E. Richards	29,105
Donald R. Andersen	28,280
John S. Pratt	29,476
A. Jose Cortina	29,733
James L. Ewing, IV	30,630
Stephen M. Schaetzel	31,418
James Dean Johnson	31,771
Charles W. Calkins	31,814
Larry A. Roberts	31,871
Jamie L. Greene	32,467
George T. Marcou	33,014
Bernard J. Graves, Jr.	33,239
Dean W. Russell	33,452
Richard T. Peterson	35,320
Charles T. Simmons	35,359
Eleanor M. Musick	35,623
Nora M. Tocups	35,717
Bruce D. Gray	35,799
Theodore R. Harper	35,890
Geoff L. Sutcliffe	36,348
Stephen B. Parker	36,631
Pat Winston Kennedy	36,970
Leona G. Young	37,266
Suzanne Seavello Shope	37,933
Mitchell G. Stockwell	39,389
Jeffery B. Arnold	39,540
Mary Anthony Merchant	39,771
Brenda Ozaki Holmes	40,339
Lisa J. Moyles	40,737
Michael J. Turton	40,852
Yoncha L. Kundupoglu	41,130

Attorney and/or Agent	Registration No.
Scott Zimmerman	41,390
Kimberly J. Prior	41,483
Alana G. Kriegsman	41,747
Theodore M. Green	41,801
J. Steven Gardner	41,772
Joni Stutman	42,173
James J. Bindseil	42,326
Heather D. Carmichael	42,389
John K. McDonald	42,860
Sima Singadia Kulkarni	43,732
Camilla Camp Williams	43,992
Christopher J. Chan	44,070
Carl B. Massey	44,224
Li K. Wang	44,393
John William Ball, Jr.	44,433
Dawn-Marie Bey	44,442
Tiep H. Nguyen	44,465
John M. Briski	44,562
Michael J. Dimino	44,657
Kristin L. Johnson	44,807
J. Jason Link	44,874
Paul E. Knowlton	44,842
Bambi F. Walters	45,197
Cheryl L. Huseman	45,392
Shelby B. Grier	45,785
Jennifer R. Seng	45,851
Vaibhav P. Kadaba	45,865
Greg Moldafsky	46,514
J. Michael Boggs	46,563
Michael K. Dixon	46,665
Kyle M. Globberman	46,730
Tywanda L. Harris	46,758
Kristin D. Mallatt	46,895
Cynthia B. Rothschild	47,040
John C. Alemanni	P47,384
Geoffrey K. Gavin	P47,591

Inventors: Friedrich LENHARD, et al.

For: "Current Sensor Working in Accordance with the Compensation Principle"

Declaration for Patent Application

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I acknowledge the above-listed attorneys and agents and their firm Kilpatrick Stockton LLP represent my employer (if I am an employee and this application has been or will be assigned to my employer) or the entity with which I have contracted (if I am an independent contractor and this application has been or will be assigned to such entity) and in such cases do not represent me individually. I further acknowledge I have not established, nor will I seek to establish, any personal attorney/client relationship with Kilpatrick Stockton LLP in connection with this application and understand that, should I require legal representation, I will obtain such, at my expense, other than through Kilpatrick Stockton LLP.

Send Correspondence to: John S. Pratt, Esq.  
Kilpatrick Stockton LLP  
1100 Peachtree Street, Suite 2800  
Atlanta, Georgia 30309-4530

Customer No. 23370

Direct telephone calls to: Kristin D. Mallatt, Esq. (404) 815-6147

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of first inventor Friedrich LENHARD  
Inventor's signature *Friedrich Lenhard* Date 13.11.2001  
Residence Brucknerstrasse 84, D-63452 Hanau, Germany  
Citizenship German DEX  
Post Office Address Same as above

Full name of second inventor Stefan SCHÄFER  
Inventor's signature *Stefan Schäfer* Date 13.11.01  
Residence Burgblick 5, D-55452 Rümmelsheim, Germany  
Citizenship German DEU  
Post Office Address Same as above

Full name of third inventor Paul MOURICK  
Inventor's signature *Paul Mourick* Date 19.11.01  
Residence Falkenstrasse 38, D-90766, Fürth, Germany  
Citizenship German DEU  
Post Office Address Same as above